BEFORE THE
FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON, D.C. 20554

IN THE MATTER OF	)
	) GEN. DOCKET NO. 90-314
AMENDMENT OF THE COMMISSION'S	)
RULES TO ESTABLISH NEW PERSONAL	) ET DOCKET No. 92-100
COMMUNICATIONS SERVICES	)
	)

TO: THE COMMISSION

COMMENTS OF
CORPORATE TECHNOLOGY PARTNERS

Corporate Technology Partners ("CTP") submits these comments in the

Commission's above-referenced proceeding to provide additional validation of the use of

narrow channel transmission combined with dynamic interference-sensing capability (the

"ISCDMA" technology) as an optimum approach to sharing of frequencies with fixed

microwave users. These comments supplement CTP's earlier ex parte comments filed in

this proceeding on July 9, 1992.

In its earlier ex parte comments, CTP demonstrated that interference-sensing is

an important and viable PCS technology that allows frequency sharing with certainty of

protection for fixed microwave users. Moreover, CTP demonstrated that this technology

should not be rejected because of erroneous conclusions regarding workability cost or

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complexity. The technical submission attached as Exhibit I to these comments,[1] an

independent study of the interference-sensing approach, prepared by TSR Technologies,

Inc. ("TSR"), further demonstrates the feasibility, cost-efficiency, and simplicity of the

ISCDMA technology.

In its July 9, 1992 ex parte comments CTP stated:

> CTP believes strongly that the best approach to gain necessary frequency for PCS while preserving a maximum amount of flexibility for existing spectrum users involves interference sensing of fixed microwave transmissions, dynamic channel allocation to non-interfering frequencies and frequency agility to allow PCS handsets and base stations to be freely moved around the U.S. The advantages of interference-sensing include increased capacity, certainty of protection for fixed microwave users and regulatory simplicity. However, the greatest advantage of interference sensing is that it would allow introduction of PCS without need to move current fixed microwave users. In fact, in most cases PCS could share with fixed microwave on a secondary user basis.

> Conceptually, the advantages of employing a technology which automatically adjusts to avoid interference to fixed microwave transmission and avoids the need to move current fixed microwave users are obvious. For purposes of practically considering this technology as a viable solution to the spectrum shortage issues discussed by numerous parties in this proceeding, however, two questions have to be addressed: Is interference sensing in fact workable? Does interference sensing add unnecessary cost and complexity?

CTP's submission also demonstrated both the workability of interference sensing and its

cost efficiency.

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[1] Exhibit I was prepared prior to the release of the Commission's Notice of Proposed Rulemaking and Tentative Decision, FCC 92-333 (released Aug. 14, 1992) ("NPRM") in this docket. It will therefore be supplemented shortly to address the specific technical proposals of the NPRM.

The technical paper submitted as Exhibit I, reflecting analysis performed by TSR on behalf of and in conjunction with CTP, verifies the previous showings of CTP and supplements them with more analytical work. The analysis clearly shows that interference sensing is indeed workable. Further, the analysis demonstrates that the technology is cost effective because very little modification would need to be made in equipment already utilizing the current CDMA technology now being produced by companies such as Qualcomm.

Moreover, while, as noted above, the TSR/CTP technical paper was prepared prior to the Commission's issuance of the NPRM, the interference sensing approach would comply with the proposed PCS technical standards set forth in paragraphs 104 et seq. and Appendix F of the NPRM. CTP's forthcoming supplemental technical paper will demonstrate this compliance. Even without such supplementation, however, it is evident that the formulas set forth in the technical paper are specifically constructed to perform the very PCS-fixed microwave interference calculations that would be required by the NPRM.

While these formulas and the interference sensing approach are proprietary, and CTP intends to seek patent protection for the technology it has developed, CTP would license the technology on reasonable terms so that interference sensing may be made available to the PCS industry and widely implemented. Significantly, this approach avoids fixed microwave interference mapping, expands capacity in frequency sharing with fixed microwave, and leads to both certainty of protection for microwave users and regulatory simplicity.

Currently, CTP is awaiting grant of an experimental license to further demonstrate through testing the workability of the technology outlined in CTP's filings and further confirm the analysis reflected in the TSR/CTP technical paper. CTP hopes that the Commission will issue the requested experimental license promptly so that CTP can initiate the next phase of its technical experiments demonstrating the feasibility and advantages of the narrow channel CDMA, interference sensing approaches designed by CTP.[2]

CONCLUSION

As shown in Exhibit I, a technical paper prepared by a premier consulting firm whose personnel's research interests have been substantially focused on PCS, interference-sensing narrow-channel CDMA technology represents an effective and cost-efficient means of facilitating and implementing spectrum co-existence by PCS and fixed microwave users. The Commission should therefore ensure that its PCS regulatory

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[2] CTP applied for this experimental license on May 4, 1992.

scheme can accommodate PCS that is implemented using the narrow channel CDMA, interference-sensing approach developed by CTP.

Respectfully submitted,

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Co-Existence of Personal Communication Systems with Fixed Operational Microwave Links Using Interference Sensing Code Division Multiple Access (ISCDMA) Technology

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Co-Existence of Personal Communication Systems with Fixed Operational Microwave Links Using Interference Sensing Code Division Multiple Access (ISCDMA) Technology

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1.0 Abstract

An approach to Personal Communication Systems (PCS) through use of the interference sensing capabilities of CDMA pilot channels plus all of CDMA paging channels is discussed in this paper. The validity of the theory of providing interference protection for fixed microwave users through ISCDMA while maintaining a good communication quality in the ISCDMA system is also demonstrated.

2.0 Introduction

Interference Sensing Code Division Multiple Access (ISCDMA) is a method that combines an interference sensing approach and spread spectrum techniques to solve the co-existence problem of Personal Communication Systems (PCS) and existing fixed microwave links. Various investigations by different companies and research groups [1], [2], [3] have shown that there is enough spectrum for initial operation of PCS without reallocating fixed microwave links to other frequencies. One important difference between the ISCDMA technology and approaches proposed by other companies is that ISCDMA will actively provide interference protection for fixed microwave users while other approaches depend passively on the careful engineering of the exclusion zone. Moreover, if ISCDMA is employed for PCS systems, the portable handset can be designed for use in any city in the country. Therefore, ISCDMA demonstrates great potential to be used in emerging Personal Communication Systems. In order to show ISCDMA technology is feasible to implement, the protection of interference from the PCS system to fixed microwave users must be guaranteed. Analysis that describes a way to provide such protection using CDMA pilot channels and paging channels is presented in this paper.

Equipment implementing Qualcomm's direct sequence code division multiple access technology (DSCDMA) is assumed in our analysis. Frequency division is

employed by dividing the available spectrum into nominal 1.228 MHz wide channels[4]. Qualcomm's technology provides four different sub-channels in each 1.23 MHz wide forward channel[4]. They are traffic channels, the synchronization channel, paging channels and the pilot channel. The pilot channel is used by the mobile to identify the base station which provides the best signal (that is the strongest and the lowest bit-error signal) at the mobile. The pilot channel is also used in power control in both directions and phase tracking, as well as for power allocation in the forward link[5]. As explained subsequently, the pilot channel can also be readily used in the ISCDMA system for interference sensing. In fact, very little modification of the Qualcomm technology is required for ISCDMA to apply. Coherent detection and non-coherent detection are used at the mobile and at the base station respectively. More specifications on Qualcomm DSCDMA can be found in references [4], [5] and other Qualcomm publications.

Most standard fixed operational microwave links have the transmit and receive frequency offset by 80MHz[2]. While reference [2] shows that some non-standard microwave links[1] exist in some cities, research in [2] finds that the highest number of non-standard microwave links found in any of the eleven largest U.S. cellular markets is only 6[2]. Therefore, we concentrate on a feasibility analysis for an ISCDMA system for the standard two-way transmission microwave links. In Section 3.0, the interference level from a single PCS two-way transmission link to a single microwave link is presented. This analysis is then expanded into the general multi-base stations/mobiles in Section 3.1. Interference sensing using pilot channels and paging channels for the ISCDMA system is demonstrated in Section 3.2. Both references [1] and [2] show that more than one microwave link operating at the same frequencies[3] in different part of a city is common. The effects of multiple microwave links using the same frequencies on the ISCDMA system is presented in Section 4.0.

3.0 Two-Way Transmission Microwave Link with one base station and one mobile

Figure 1 shows a general interference situation between the PCS system and fixed microwave stations. In the figure, BS represents a PCS base station and MICRO represents a microwave tower. In general, there will be more than one microwave link and more than one base station and mobile in the market. In this section, we will study the coupling of energy between the microwave link and the PCS system with the most simple form, i.e. a single two-way transmission link in each system. We can then expand the analysis to more general cases.
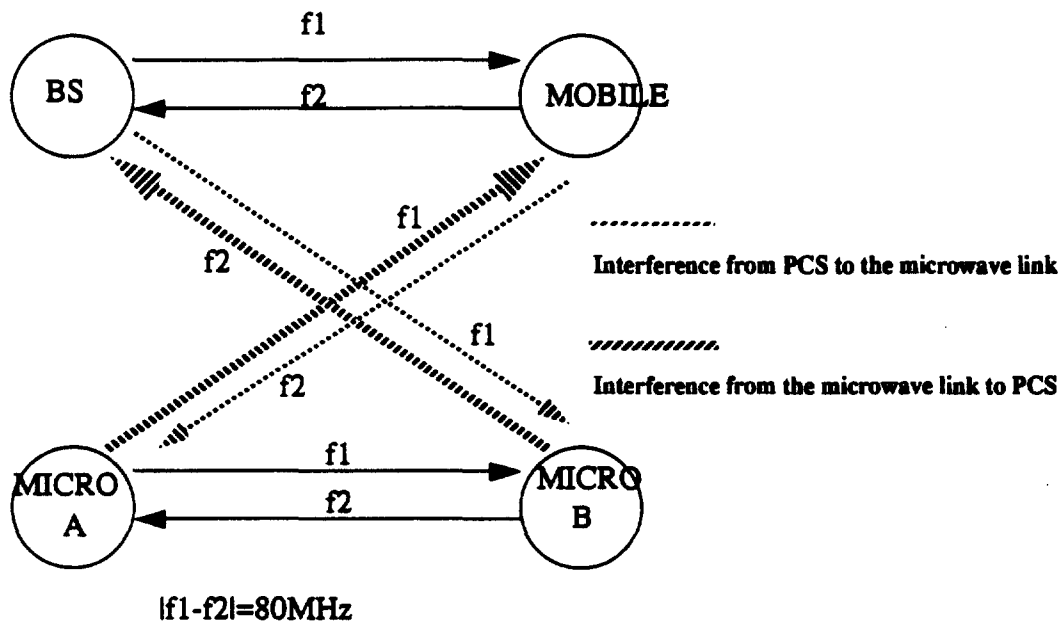
In the figure, microwave station A transmits frequency f1 and receives frequency f2 while microwave station B transmits frequency f2 and receives frequency f1. For the PCS system, the base station transmits frequency f1 and receives frequency f2 while the

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1. either simplex or not following standard channel plan
2. Los Angeles
3. reverse channel and forward channel

mobile transmits frequency f2 and receives frequency f1[4]. Four sources of interference between the PCS system and the microwave link are possible.

- Interference from Microwave Station A to the mobile $I_{A/mobile}$

- Interference from Microwave Station B to the base station $I_{B/BS}$

- Interference from the mobile to Microwave Station A $I_{mobile/A}$

- Interference from the base station to Microwave Station B $I_{BS/B}$

FIGURE 1. Mutual Interference of Microwave Link (two way transmission) and PCS system

Interference from PCS to the microwave link

Interference from the microwave link to PCS

|f1-f2|=80MHz

If there are more than one base station and more than one mobile in the system, there will be additional interference to the microwave link as well as within the PCS system. This will be discussed later. For the present discussion, we assume there are only one mobile and one base station in the PCS system. For the ISCDMA system, the base station can scan the entire frequency band and measure the interference power from the microwave station B[5], $I_{B/BS}$, and if the maximum transmitter power of the microwave

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4. Alternatively, the base station can transmit frequency f2 and receive frequency f1 while the mobile transmits frequency f1 and receives frequency f2. In order to provide maximum isolation between the PCS system and the microwave link, the base station and the mobile should transmit at frequencies that have minimum mutual interference between the PCS system and microwave users. In Figure 1, we assume that $I_{A/BS}$ is larger than $I_{B/BS}$.

5. The base station also measures the interference from the microwave station A. For the above discussion, we assume $I_{B/BS}$ is smaller than $I_{A/BS}$ and therefore the base station decides to transmit frequency f1 rather than frequency f2.

station B is known, then the path loss from microwave station B to the base station can be calculated from the measured signal level from the microwave tower.

$$I_{B/BS}(dB) = Pt(B) - PL_{B/BS} + G_B + G_{BS} \quad \text{(EQ 1)}$$

where $Pt(B)$ is the power transmitted by microwave station B, $PL_{B/BS}$ is the measured path loss from microwave station B to the base station. G_B, G_{BS} are the antenna gains of microwave station B, and the base station respectively. It should be noted that $I_{B/BS}$ is based on the known characteristics of the microwave transmitter and is a static quantity, subject to small changes due to measured signal strength.

If PCS channels are assumed to be reciprocal[6] and f1/f2 is close to unity, then the path loss from the microwave station B to the base station is virtually the same as that from the base station to the microwave station B. If the transmitter power of the base station is known, the corresponding average interference power from the base station to the microwave station is given by:

$$I_{BS/B}(dB) = I_{B/BS} - Pt(B) + Pt(BS) \quad \text{(EQ 2)}$$

where $Pt(BS)$ is the power transmitted by the base station.

It is desirable to have the interference power level from the PCS system to the microwave links to be small. One standard is that the interference power should be 6 dB below the thermal noise level[7]. The maximum interference threshold is denoted as Th. In order to protect the microwave link from interference caused by the PCS system, the following inequality must be satisfied.

$$I_{B/BS}(dB) \leq Th + Pt(B) - Pt(BS) \quad \text{(EQ 3)}$$

If the base station determines that equation (3) is satisfied, it can transmit frequency f1 without interfering with microwave station B. This information can then be sent to the mobile via the paging channel. The mobile then needs to determine whether the interference from microwave station A is small enough to protect microwave station A from interference while maintaining a good communication quality in the PCS system. The figure of merit for determining the quality of transmission of a CDMA signal is the bit energy to noise density ratio (Eb/No). Eb/No at the mobile is given by:

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6. It is well known that path loss in mobile propagation channels is characterized by a log-normal large scale path loss superimposed by a small scale Rayleigh fading[10]. While large scale path loss is not sensitive to small frequency change, small scale fading is extremely sensitive to frequency change because it is prima-rily a phenomenon of superposition of multipath components with different amplitudes and phases, which can change significantly even if frequency changes by little. However, references [8] and [9] show that rms delay spread in microcellular propagation environment varies from a few hundred nanoseconds to a few microseconds, depending on the location, the T-R separation and other factors. Assuming a rms delay spread value of 500 ns, which corresponds to a coherence bandwidth of 200kHz[10], a 1.25 MHz bandwidth can therefore offer frequency diversity. Thus, it is justified that the path loss is reciprocal between the base station and the microwave station although frequencies are offset by 80MHz.

$$\left(\frac{E_b}{N_o}\right)_{mobile} = \frac{Pr_{mobile}/R}{(I_{A/mobile} + \eta)/W} = \frac{Pr_{mobile} \bullet PG}{I_{A/mobile} + \eta} \qquad \text{(EQ 4)}$$

where PG is the processing gain[7], Pr_{mobile} is the power of the desired signal received at the mobile which is a function of transmitter power of the base station, location of the mobile, and the propagation model, and η is thermal noise power[8]. It is clear from equation (4) that if $I_{A/mobile}$ is much larger than Pr_{mobile}, the communication quality at the mobile may not be acceptable.

The interference power $I_{A/mobile}$ is measured at the mobile. The methodology to measure $I_{A/mobile}$ by pilot channels will be presented in section 3.2. Similar to the above derivation, microwave station A is protected from interference caused by the PCS system if the following inequality is satisfied.

$$I_{A/mobile}(dB) \le Th + Pt(A) - Pt(mobile) \qquad \text{(EQ 5)}$$

Equations (3) and (5) guarantee protection of microwave users from the PCS interference. The measured interference powers from the microwave station B to the base station and from the microwave station A to the mobile are used in equations (3) and (5) to determine if the interference from the PCS system to the microwave link is below threshold Th or not.

Horizontal polarization is used for half of microwave links [3] while vertical polarization is likely to be used in PCS systems. The polarization mismatch of the two systems can provide an extra protection for microwave users. However, we cannot rely on polarization to provide sufficient isolation between the two systems because depolarization of electromagnetic waves in a non-line-of-sight channel is generally high. If channels are assumed to be reciprocal, equations (2) to (5) can be applied without modification to include polarization effects.

3.1 Multiple Base Stations and Multiple Mobiles

If there are more than one mobile and more than one base station transmitting frequency f1 and receiving frequency f2 in the area of interest, then the interference power from the PCS system to the microwave system will definitely be higher than obtaining in the single base station/single mobile case. The interference level within the PCS system will be higher as well. The summed power of the transmission at the base station can increase as subscriber demand increases, causing increasing interference to the microwave users, whereas this could not occur in "normal" demand load operation. The interaction between multiple base stations with multiple mobiles and a single two-way microwave

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7. Bit rate of 8kb/s is that of an acceptable toll quality vocoder which gives processing gain, PG, to be equal to 154 [4].

8. Thermal noise power is equal to the thermal noise spectral density (η_o) multiplied by the total spreading bandwidth W.

link is considered in this section. By repeating the same argument for different microwave links, the capacity and performance of the ISCDMA system can be obtained.

Assume there are N mobiles that transmit frequency f2 and receive f1 within the area of interest, and there are M base stations in the area. The total interference power (in linear scale) from the PCS to the microwave station A, $I_{PCS/A}$, can be given by:

$$I_{PCS/A} = \left(\sum_{i=1}^{N} \frac{I_{A/M_i} Pt(M_i)}{Pt(A)} \right) \frac{BW}{1.23} \leq Th \qquad \text{(EQ 6)}$$

where I_{A/M_i} is interference power from the microwave station A to the i-th mobile and $Pt(M_i)$ is the power transmitted by the i-th mobile. It should be noted that the interference to the microwave station should be multiplied by a factor[9] of $BW/1.23$ where BW is the operating bandwidth(MHz) of the microwave station A and 1.23 denotes the bandwidth of the Qualcomm CDMA signal.

Similarly, the total interference (in linear scale) from the PCS system to the microwave station B, $I_{PCS/B}$, is as follows.

$$I_{PCS/B} = \left(\sum_{i=1}^{M} \frac{I_{B/BS_i} Pt(BS_i)}{Pt(B)} \right) \frac{BW}{1.23} \leq Th \qquad \text{(EQ 7)}$$

where I_{B/BS_i} is the interference power from the microwave station B to the i-th base station and $Pt(BS_i)$ is the power transmitted by the i-th base station[10]. Interference power from the microwave station B to each base station can be measured prior to the operation of the PCS system or can be performed on a regular basis. Therefore, to keep track of the total interference from PCS system to the microwave link, there must be stored in each base station the interference power from microwave station B to each base station, the transmitter power of the microwave station and its operating bandwidth. Also, the difference between Th and $I_{PCS/A}$ as well as the difference between Th and $I_{PCS/B}$ should always be *larger* than zero in order to not interfere with microwave station A and B. Finally, the difference between Th and $I_{PCS/A}$ should be passed to the mobile over the paging channels to allow computation of interference from mobile units. Additional means for keeping track of the total interference from the PCS to the microwave link will be presented in the next section.

Hence, in order to provide protection for the microwave system, $I_{PCS/A}$ and $I_{PCS/B}$ must be less than the required threshold. Every time a new call setup is requested, the

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9. There is more than one CDMA reverse channel within the operating bandwidth of microwave station A. The total interference power from the PCS system to the microwave station A includes interference power from all reverse channels within the operating bandwidth of the microwave station A. In equation (6), we assume the interference power caused by each reverse channel is the same.

10. $Pt(BS_i)$ is the power transmitted by the base station i for one forward channel only. In equation (7), we assume $Pt(BS_i)$ for forward channels within the operating bandwidth of the microwave station B are the same.

interference power from the PCS system to the microwave link must be calculated and ensure it is lower than the threshold. Similarly, every time a call is completed, the interference power must be updated as well. However, these two inequalities[11] are not alone sufficient to ensure frequencies f1 and f2 are good for operation within the PCS system because interference power from the microwave link to the PCS system may be too high for the PCS system to have a good communication quality. Consider the reverse link again (from the mobile to the base station). If perfect power control is assumed in the reverse link, then the bit energy to the noise density level[12] at the base station j, $(Eb/No)_{BSj}$, is given by[13]:

$$\left(\frac{E_b}{N_o}\right)_{BS_j} = \frac{P_{R_j} \bullet PG}{(N'-1)P_{R_j} + I_{B/BS_j} + I_{out} + \eta} \leq \left(\frac{E_b}{N_o}\right)_{system} \tag{EQ 8}$$

where N' is the number of mobiles within the cell of interest, PG is the processing gain, I_{out} is interference power due to mobiles that are outside the cell, $(Eb/No)_{system}$[14] is the minimum system performance required, and P_{Rj} is the power received at the base station j due to each mobile with prefect power control. The ratio between the in-cell noise to total received noise, not including the microwave interference power, is known as the frequency re-use factor[6]. Some analysis of the frequency re-use factor is presented in [6]. However, the results of [6] are not directly applicable to the case here because a uniform distribution of users was assumed in [6] while there should be more users far away from the microwave link in order to maximize capacity of the ISCDMA system. If the power received at the base station due to each mobile within the cell, the maximum allowable transmitter power by each base station,[15] and the interference power from microwave station B are known, then the maximum allowable users in each cell[16] can be computed from equation (8).

If P_{Rj} is very large compared to $I_{B/BSj}$, then the effect of interference from the microwave station B to the PCS system on the bit energy to noise density ratio at the base station can be ignored. However, increasing P_{Rj} will increase interference on microwave station A due to the mobile since P_{Rj} and $Pt(M_i)$ are related by the following equation:

$$P_{R_j}(dB) = Pt(M_i) - PL_i \tag{EQ 9}$$

11. $I_{PCS/A} \leq Th$ $I_{PCS/B} \leq Th$

12. The bit error rate (BER) performance, which can be measured at the base station and the mobile, is a function of (Eb/No). By measuring BER, we can obtain the value of (Eb/No) if the modulation characteristics are known.

13. Voice activity gain and sectorization gain are ignored to simplify analysis

14. 5dB to 7dB according to reference [5]

15. The maximum allowable transmitter power depends on the interference power from the microwave station B to that base station. A way to compute the maximum allowable power is presented in the next section.

16. The maximum allowable users in each cell should be different. Cells far away from the microwave link should allow more users than cells close to the microwave link.

where PL_i is the propagation loss (absorbing antenna gains) between the i-th mobile (i=1,2, .. , N') and base station j. An appropriate value of P_{Rj} can be computed such that the interference on the microwave link is tolerable while the capacity of the system is maximized.

Equation (8) ensures the signal quality at the base station (reverse link) is better than the minimum tolerable quality and together with equation (6) confirms frequency f2 at the reverse link will not cause excessive interference to the microwave station A while maintaining acceptable transmission quality.

If interference sensing through pilot channels is to give sufficient protection for the microwave link, pilot channels must become unusable at a threshold where the microwave link is guaranteed no detectable interference will occur to the fixed microwave link. Furthermore, the Eb/No value of the pilot channel should be above a certain level in order to maintain a good transmission quality for the forward link. This particular level will be studied as follows. First, the Eb/No ratio of the pilot channel of base station i at the j-th mobile, $(Eb/No)_{pilot\ i,j}$, is lower bounded by[5]:

$$\left(\frac{E_b}{N_o}\right)_{pilot_{i,j}} \geq \frac{(1-\beta)\,Pr_{i,j} \bullet PG}{\left(\sum_{i=1}^{M} Pr_{i,j}\right) + I_{A/M_j} + \eta} \qquad \text{(EQ 10)}$$

where β is the amount of power devoted to the subscribers (1-β devoted to the pilot) and $Pr_{i,j}$ is the power received at the j-th mobile due to the i-th (i=1,2, ..,M) base station.

The Eb/No ratio of the information bearing channel at the j-th mobile communicating with the i-th base station is lower bounded by:

$$\left(\frac{E_b}{N_o}\right)_{mobile_{i,j}} \geq \frac{\beta \Phi Pr_{i,j} \bullet PG}{\left(\sum_{i=1}^{M} Pr_{i,j}\right) + I_{A/M_j} + \eta} \geq \left(\frac{E_b}{N_o}\right)_{system} \qquad \text{(EQ 11)}$$

where Φ is the portion of the power devoted to the subscriber of interest. Combining equations (10) and (11), we have the following ratio:

$$\frac{(E_b/N_o)_{pilot_{i,j}}}{(E_b/N_o)_{mobile_{i,j}}} = \frac{1-\beta}{\beta\Phi} \qquad \text{.(EQ 12)}$$

Equation (12) relates the bit energy to noise density ratio of the pilot channel to that of the forward traffic channel. Hence, a threshold that incorporates equation (12) can be designed at the mobile to reject an unusable forward channel. The mobile receiver scans through all pilot channels. If the first pilot channel has low power or exhibits bit error transmission problems, the subscriber terminal continues the scan until it finds a pilot channel with strong power and low bit error rate. However, these are not sufficient criteria

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for selection of the traffic channel because the interference from the PCS system to the microwave link may be high. Equations (6), (7), (8) and (11) must be satisfied *simultaneously* if a frequency pair f1/f2 is functional in the PCS system while the interference to the microwave station is tolerable. The pilot channel and paging channel are used to satisfy these four requirements as will be discussed in the next section.

3.2 Interference Sensing by Pilot Channels

The criteria for determination of "tolerable" interference caused by PCS on microwave users have been presented in the last section (equations 6&7). The transmission quality at the mobile and at the base station have been explained (equations 8&11). Four criteria must be satisfied if a duplex CDMA channel is to be deemed *usable* for communication between the base station and the mobile:

- total interference from PCS to the microwave station A is below threshold

- total interference from PCS to the microwave station B is below threshold

- transmission quality of the forward link of PCS is above a particular performance level

- transmission quality of the reverse link of PCS is above a particular performance level

First consider the forward link, i.e. from the base station to the mobile. We have demonstrated that the total interference from the PCS system to the microwave station B is given by equation (7). Therefore, if interference caused by each base station on the microwave station B is less than Th/M, where M is the total number of base stations, then the total interference from the PCS system to the microwave station B is less than threshold and satisfies the second criterion above. If the maximum allowable power at a particular base station is less than the minimum power to set-up a traffic channel[17], then the forward channel is considered *unusable* in that cell. Suppose the channel is unusable for the forward link in L cells[18], the maximum allowable transmitter power[19] by each base station is given by:

$$Pt(BS_i) \leq \frac{ThPt(B)}{(M-L)I_{B/BS_i}}$$ (EQ 13)

The maximum allowable transmitter power of the base station is large if the interference caused by microwave station B onto that base station is small, and vice versa. The total allowable transmitter power includes power for all forward channels, i.e., traffic channels, pilot channels, synchronization channels and paging channels, that are within the operating bandwidth of the microwave link. Equation (13) provides one way to divide the allowable transmitter power of base stations by making interference powers from each

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17. The minimum power to set-up a traffic channel includes power for each of the pilot channel, the synchronization channel, the paging channel, and the traffic channel.[4]

18. L, $I_{B/BSi}$ are fixed quantities

19. Include power of all forward channels within the operating bandwidth of microwave station B of each base station

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base station to the microwave station B the same. If there are high demands in one particular cell, the allowable transmitter power of the base station can be increased by decreasing the maximum allowable power in cells with less demand. The total interference power on the microwave station is below the specified threshold as long as equation (7) is satisfied.

Each base station needs to follow two steps to determine if the forward traffic channel, with an additional mobile, is still usable or not. As a first step, the base station should estimate the total interference on the microwave station B if an additional mobile is put into the cell. If the total interference of the forward link on microwave station B (which is increased by an extra mobile in the cell) is still below the threshold and the additional user does not cause a degradation of transmission quality of the reverse link to be below a certain performance level, then the forward traffic channel, with an additional mobile, is still usable. If one or both conditions are violated, the base station should indicate to the mobile[20] that the forward traffic channel is not available. To sum up, the following two criterion must be satisfied simultaneously if the forward traffic channel, with an additional mobile, is to be usable.

• the total interference by the forward link of the PCS system onto the microwave station B, with the additional interference caused by the extra user, is still within the required threshold

• the transmission quality of the reverse link, with the additional mobile, will be above the specified performance level

The first condition mentioned above can be checked by equation (7) while the second condition can be checked by equation (8). Two remaining criteria must be checked at the mobile.

The interference caused by the microwave station A on the mobile is estimated via the quality of pilot channels. Signals from different base stations are distinguished by pseudo-random noise (PN) code with different time offsets[4]. The mobile unit acquires the strongest pilot by searching (correlating) all 32768 time shifts of the PN code. Based on these measurements, there are M+1 unknowns, P_{r1}, P_{r2}, .., P_{rM}, and $I_{A/M}$. Since there are more than M+1 equations with M+1 unknowns, $I_{A/M}$ can be determined uniquely. It can be shown that the solution is quite simple[21]. Assuming $I_{A/M}$ is known based on these measurements at the mobile, the mobile then can determine if equation (6) is satisfied[22], with the additional mobile. If equation (6) is satisfied, then criterion number one at the beginning of this section is satisfied. Next, the mobile needs to check if the Eb/No of the information bearing channel is above the specified threshold or not. This can be done by applying equation (12) which relates the bit energy to noise density ratio of the

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20. One way to do this is to embed the information into the paging channel.

21. Numerical methods such as Gaussian Elimination are not needed. The exact algorithm to determine interference from microwave users to PCS depends on the specific parameters of pilot channel strength measurement which are proprietary to Qualcomm.

22. The original value of interference power from mobiles (without the additional mobile) to the microwave station A can be passed to the new mobile via the paging channel.

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pilot channel to that of the forward traffic channel. Figure 2 gives a simple algorithm which explains how the above procedures can be implemented at base stations and mobiles. A microprocessor that performs all the above computations can be designed and implemented at the mobile unit[23]. Equation (6) requires knowledge of the transmitter power of microwave station A, its bandwidth and the original interference power from PCS to the microwave station A (without the additional mobile). This information can be obtained from the base station via the paging channel. However, this introduces complexity in the mobile unit. An easier way which allows the mobile unit to provide interference protection for microwave station A is through threshold design into the mobile unit. If a worst case design is used, no information needs to be transmitted from the base station to the mobile unit. Methodology of a worst case design is presented in the next section.

3.2.1 Worst Case Interference Threshold Design

There are two types of interference experienced by a mobile unit: interference from neighboring base stations and interference from the microwave station A. Therefore, it is *impossible* to compute actual interference power due to microwave station A based on a single pilot quality (strongest pilot) measurement[24]. However, it is possible to provide an upper bound of interference power from the microwave station A to PCS by assuming microwave station A being the only source of interference and in turn set a threshold for interference power from mobile units to microwave station A. This solution trades simplicity in the mobile unit for a certain loss of capacity. Assuming for the purpose of setting the necessary interference threshold that all interference received by PCS mobile units is caused by microwave station A, interference from microwave station A to PCS should not exceed the worst case interference threshold, *Th_Interference*, in order to provide interference protection for microwave users. If the interference power from mobiles to the microwave station A is divided equally among each mobile, then the worst case interference threshold is given by:

$$I_{A/M_i} \leq \frac{ThPt(A)_{min}}{N_{max}Pt(M_i)_{max}\gamma_{max}} = Th\_interference \qquad \text{(EQ 14)}$$

where γ_{max} is maximum value of BW/1.23, $Pt(A)_{min}$ is the minimum transmitter power used by microwave station A, $Pt(M_i)_{max}$ is the maximum transmitter power of the mobile unit and N_{max} is the maximum number of mobiles in the PCS system. Therefore, the right hand side of equation (14) provides a worst case (minimum) interference threshold. Interference from microwave station A to the mobile, $I_{A/Mi}$, must not exceed *Th_interference* if the microwave station A is guaranteed interference protection. All parameters in equation (14), except N_{max}, can be found by checking the specifications of microwave stations and mobile units. The main difficulty lies in the setting of N_{max}. If

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23. With the advance of microprocessor technology, the above computations can be done easily and economically.

24. Hence, it is not possible to assign a bit-error rate (BER) threshold for the strongest pilot channel such that microwave station A is guaranteed protection.

N_{max} is set very small, the system capacity will be limited. On the other hand, if N_{max} is set too large, the threshold may be too "tight" (i.e., threshold being too small) so that some usable reverse channels are rejected from use. Further study is required to determine an optimum value of N_{max}. Also, the degradation of capacity, using a worst case interference threshold, needs to be studied as well[25]. This will be done through further analysis to be submitted to the Commission.

4.0 Multi-Microwave Links Sharing Same Frequencies

In this section, we expand the analysis of section 3.0 and combine it with the analysis of section 3.1. That is, the single microwave link is generalized to multi-microwave links sharing the same frequencies with multiple base stations/mobiles. However, only the concept rather than the mathematical detail is presented because the equations for this case are very similar to those in the last two sections. Assume there are K microwave links sharing the same frequencies and denote the stations of each link as Ai, Bi for i=1,2,.., K. All the analysis preformed above remains valid if the following steps are followed.

4.1 Estimation of Path Loss Between Each Microwave Link and Each Base Station

The total interference power from microwave users to the base station is a superposition of interference powers from each microwave user sharing the same frequencies. Therefore, the measurement of interference power at the base station is a sum of interference powers from each microwave station. Equation (1) is modified as follows to include effects of multiple microwave stations.

$$I_{MICRO/BS_j} = \sum_{i=1}^{K} \frac{Pt(B_i)}{PL_{B_i/BSj}} \qquad \text{(EQ 15)}$$

where $I_{MICRO/BSj}$ is the interference power from all microwave users to the base station j, $PL_{Bi/BSj}$ is the propagation loss (absorbing antenna gains) from the microwave station Bi to the base station j. It is easy to show that the propagation loss from each microwave station Bi to the base station j is always larger than $Pt(Bi)/I_{MICRO/BSj}$. Therefore, we have a minimum path loss between the base station and each microwave station and the maximum interference power from each base station to each microwave user can be computed. A similar equation can be derived for the propagation loss between each mobile and each microwave station.

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25. It is clear that the approach presented in Section 3.2 is more complicated than that of Section 3.2.1. The capacity of the former approach will be higher than that of the latter one. Hence, there is a trade-off between complexity and capacity. If the values of Pt(A) and γ do not vary by much, however, the system capacity using the latter approach will be close to the capacity using the former approach.

4.2 Interference Protection

Interference protection for microwave stations can be achieved by applying (6) and (7) for all the microwave stations. That is, A and B in equations (6) and (7) becomes Ai and Bi, and we need to determine if equations (6) and (7) are satisfied or not for K times.

4.3 PCS Communication Quality

The criteria for good communication quality of the PCS system is the same as before. No matter whether there is one microwave link or there are multiple microwave links sharing the same frequencies, equations (8) and (11) must be satisfied in order to provide the minimum performance level. The only modification in equations (8) and (11) is that the sum of the interference power from multiple microwave stations must appear in the denominator rather than just interference from only a single microwave station.

5.0 Conclusion

We have established criteria for a frequency-division CDMA duplex channel to have tolerable interference to microwave links while maintaining a good communication quality in the PCS system. By measuring interference power at the base station and assuming reciprocity of path loss holds for forward and reverse channels, the interference power to the microwave station can be estimated if its transmitted power is known. The pilot channel as well as the paging channel are used to ensure all the criteria explained in section 3.2 are satisfied simultaneously. At the mobile, the communication quality of the forward link can be estimated by measuring the transmission quality of the pilot channel. If the transmission quality of the pilot channel is above a certain threshold, then the mobile needs to check whether the mobile will cause excessive interference to microwave users. Therefore, the transmit and receive frequencies of microwave links as well as their corresponding transmitter powers and operating bandwidths must be stored at each base station. This information then needs to be sent to the mobile via the paging channel. Alternatively, for simplicity in the mobile unit, a worst case interference threshold can be used to ensure interference protection for microwave users while avoiding transmission of microwave station parameters from the base station to the mobile unit. No interference mapping is required since all interference computations are done autonomously at base stations and mobiles. Also, we have discussed briefly how to expand the model to include the effects of multiple microwave stations sharing the same frequencies. Hence, we have demonstrated how ISCDMA can be used to solve the co-existence problem of the PCS system and fixed operational microwave users. It is clear that ISCDMA is a cost-efficient method since minimum modification of current Qualcomm technology is required and no frequency availability map is needed. Moreover, this approach provides certainty of protection for fixed microwave users, and allows co-primary or even secondary use of the 1850-1990MHz band by a PCS system. Therefore, ISCDMA is an efficient and effective spectrum sharing technology for the emerging Personal Communication Systems.
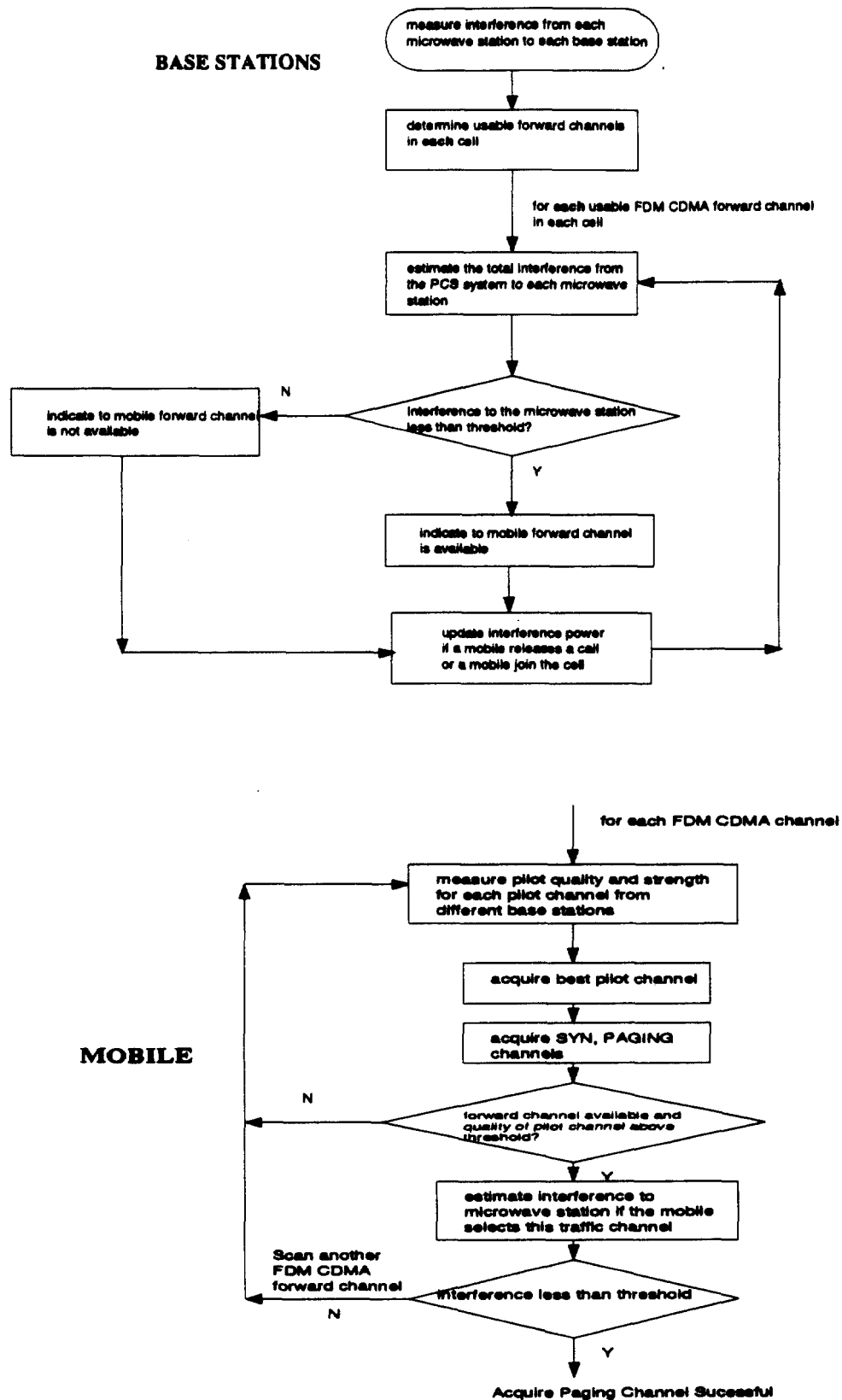
BASE STATIONS

```
        ┌──────────────────────────────┐
        │  measure interference from each │
        │  microwave station to each base station │
        └──────────────┬───────────────┘
                       │
                       ▼
        ┌──────────────────────────────┐
        │  determine usable forward channels │
        │  in each cell                 │
        └──────────────┬───────────────┘
                       │   for each usable FDM CDMA forward channel
                       │   in each cell
                       ▼
        ┌──────────────────────────────┐
        │  estimate the total interference from │◄────────────┐
        │  the PCS system to each microwave │              │
        │  station                      │              │
        └──────────────┬───────────────┘              │
                       │                               │
                       ▼                               │
    ┌────────────┐  N  ◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇            │
    │ indicate to mobile forward channel │◄── Interference to the microwave station │
    │ is not available │     less than threshold?  ◇◇◇            │
    └──────┬─────┘     ◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇            │
           │                      │ Y                             │
           │                      ▼                               │
           │         ┌──────────────────────────────┐           │
           │         │  indicate to mobile forward channel │     │
           │         │  is available                 │           │
           │         └──────────────┬───────────────┘           │
           │                        │                            │
           │                        ▼                            │
           │         ┌──────────────────────────────┐           │
           └────────►│  update interference power    │───────────┘
                     │  if a mobile releases a call  │
                     │  or a mobile join the cell    │
                     └──────────────────────────────┘
```

MOBILE

```
                        │  for each FDM CDMA channel
                        ▼
        ┌──────────────────────────────┐
        │  measure pilot quality and strength │◄─────┐
        │  for each pilot channel from  │      │
        │  different base stations      │      │
        └──────────────┬───────────────┘      │
                       ▼                       │
        ┌──────────────────────────────┐      │
        │  acquire best pilot channel   │      │
        └──────────────┬───────────────┘      │
                       ▼                       │
        ┌──────────────────────────────┐      │
        │  acquire SYN, PAGING          │      │
        │  channels                     │      │
        └──────────────┬───────────────┘      │
                       ▼                       │
  N  ◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇                  │
◄──── forward channel available and │          │
      quality of pilot channel above │         │
      threshold?   ◇◇◇◇◇◇◇◇◇◇◇◇◇      │         │
                       │ Y                      │
                       ▼                        │
        ┌──────────────────────────────┐       │
        │  estimate interference to     │       │
        │  microwave station if the mobile │    │
        │  selects this traffic channel │       │
        └──────────────┬───────────────┘       │
                       ▼                        │
Scan another    ◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇            │
FDM CDMA    ◄──── interference less than threshold ◇◇◇
forward channel  ◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇◇
      N                │ Y
                       ▼
        Acquire Paging Channel Successful
```

FIGURE 2. Interference Sensing in the ISCDMA system

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Nestled in the heart of the Appalachian mountains, a quiet revolution is taking place. A new breed of wireless communications engineer is being developed on the campus of Virginia Tech, Virginia's largest university located in Blacksburg. In 1990, Virginia Tech launched the Mobile and Portable Radio Research Group (MPRG), a center for education and research excellence in cellular radio and PCN. MPRG involves five electrical engineering faculty and over 25 students and professionals who are dedicated to solving problems in wireless communications. TSR Technologies is a natural spin-off from the wireless research program in the University's electrical engineering department. The company has been providing clients with fast and accurate measurements, research, and development results for over three years, while providing undergraduate and graduate students an opportunity to consult for major corporations.

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BIOGRAPHICAL SKETCH OF THEODORE S. RAPPAPORT (7/92)

Theodore S. Rappaport was born in Brooklyn, NY on November 26, 1960. He received B.S.E.E, M.S.E.E, and Ph.D. degrees from Purdue University in 1982, 1984, and 1987, respectively. In 1988, he joined the Electrical Engineering faculty of Virginia Tech, Blacksburg, where he is an associate professor and director of the Mobile and Portable Radio Research Group. Prof. Rappaport conducts research in mobile radio communication system design and RF propagation prediction through measurements and modeling. He guides a number of graduate and undergraduate students in mobile radio communications, and has authored or coauthored more than 70 technical papers in the areas of mobile radio communications and propagation, vehicular navigation, ionospheric propagation, and wideband communications. He holds a U.S. patent for a wide band antenna and is co-inventor of SIRCIM, an indoor radio channel simulator that has been adopted by over 50 companies and universities. In 1990, he received the Marconi Young Scientist Award for his contributions in indoor radio communications, and was named a National Science Foundation Presidential Faculty Fellow in 1992. He is an active member of the IEEE, and serves as senior editor of the IEEE Journal on Selected Areas in Communications. He is a Registered Professional Engineer in the State of Virginia and is a Fellow of the Radio Club of America. Dr. Rappaport is also president of TSR Technologies, a cellular radio and paging test equipment manufacturer.

Peter Chung-Man Ho was born in Hong Kong on October 13, 1970. He received a B. Sc. degree in electrical engineering from Virginia Polytechnic Institute and State University in 1991. In September 1990, he joined the Optical Image Processing Lab of Virginia Polytechnic Institute and State University where he served as an undergraduate research assistant. In August 1991, he joined the Mobile and Portable Radio Research Group (MPRG) of Virginia Tech where his graduate research focused on indoor propagation for future Personal Communication Systems. His research interest includes Personal Communication Systems, antenna design, propagation prediction, and optical image processing.

Mr. Ho is a member of Tau Beta Pi.